March 22, 2004

POPULAR SUMMARY --

"Processes affecting Tropospheric Ozone over Africa"

A Workshop Report on "Tropospheric Ozone over Africa"
Held in Durban, South Africa in January 2004; Hosted by R. D. Diab

To be submitted to *Eos, Trans. AGU*

Authors
***Roseanne D. Diab,* University of KwaZulu-Natal, Durban, South Africa and**
***Anne M. Thompson,* NASA/Goddard Space Flight Center, Greenbelt, Md, USA.**

This is a Workshop Report prepared for Eos, the weekly AGU magazine. The workshop took place between 26-28 January 2004 at the University of KwaZulu-Natal in Durban, South Africa and was attended by 26 participants (http://www.geography.und.ac.za). Considerable progress has been made in ozone observations except for northern Africa (large data gaps) and west Africa (to be covered by the French-sponsored AMMA program). The present-day ozone findings were evaluated and reviewed by speakers using Aircraft data (MOZAIC program), NASA satellites (MOPITT, TRMM, TOMS) and ozone soundings (SHADOZ). Besides some ozone gaps, there are challenges posed by the need to assess the relative strengths of photochemical and dynamic influences on the tropospheric ozone budget. Biogenic, biofuels, biomass burning sources of ozone precursors remain highly uncertain. Recent findings (by NASA's Chatfield and Thompson, using satellite and sounding data) show significant impact of Indian Ocean pollution on African ozone. European research on pollutants over the Mediterranean and the middle east, that suggests that ozone may be exported to Africa from these areas, also needs to be considered.

NASA HQ Program Sponsors: ACMAP, TOMS

Submitted to Eos

Processes affecting Tropospheric Ozone over Africa: Report on workshop held in Durban, South Africa in January 2004

Authors
Roseanne D. Diab, University of KwaZulu-Natal, Durban, South Africa and *Anne M. Thompson,* NASA/Goddard Space Flight Center, Greenbelt, Md, USA.

Roseanne D. Diab
diab@ukzn.ac.za
University of KwaZulu-Natal,
School of Life and Environmental Sciences
Durban 4001, South Africa
Tel – 27-31-260-2300; fax – 27-31-260-1391

Anne M. Thompson
Thompson@gator1.gsfc.nasa.gov
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
Tel – 301-614-5731; fax – 301-614-5903

The continent of Africa has a rich and complex mixture of ozone precursor emissions and a large land mass in the tropics where photochemical activity is high, all of which contribute to the distinct regional and seasonal features of tropospheric ozone over the continent. Biomass burning has long been known to exert a major influence on tropospheric ozone, with Northern Hemisphere (NH) biomass burning peaking between December and February (DJF) and Southern Hemisphere (SH) biomass burning spreading eastwards and southwards between June and October. Biogenic emissions from vegetation and soils are also regarded as significant, with the pulsing experienced after the first spring rains being particularly important. Lightning production of NO_x is recognized as amongst the highest in the world. Urban-industrial emissions too, are not insignificant. Over West Africa, there are major urban centers such as Lagos and Abidjan, and the occurrence of extensive oil refining activities. The highly industrialized South African highveld region, with its major urban centres (Johannesburg, Pretoria) and concentration of coal burning thermal power plants, and the heavily polluted city of Cairo are other areas where urban-industrial emissions are important. Features of African cities include lower transportation and industrial emission controls and use of dirty fuels. Added to this diversity in sources, is the use of domestic biofuels (wood, coal, kerosene) for cooking and heating.

Dynamics too, contribute to the complexity of the tropospheric ozone picture, particularly the seasonal and regional variability. The large meridional extent of the continent and extensive land mass in the tropics, provides opportunities for a mix of mid-latitude and tropical dynamic influences and inter-hemispheric exchanges. The juxtaposition of two large oceans to the east and west also emphasizes the contrast between continental and oceanic influences and facilitates ready identification of important intercontinental transport pathways.

Challenges posed by the need to assess the relative strengths of photochemical and dynamic influences on the tropospheric ozone budget prompted the organization of a workshop on "Tropospheric Ozone over Africa" that provided a forum to address these issues. The workshop took place between 26-28 January 2004 at the University of KwaZulu-Natal in Durban, South Africa and was attended by 26 participants from 4 different countries (see http://www.geography.und.ac.za for a list of participants and workshop presentations) (Plate 1).

Major themes included regional ozone status reports, photochemical and dynamical influences, intercontinental transport, ozone variability and presentations on future measurement campaigns.

Regional status reports highlighted contrasts between north and south, east and west and the interplay between dynamic and photochemical influences. In the West African Gulf of Guinea coast (Abidjan, Lagos), high ozone peaks (70 ppbv)) occurred in the lower troposphere (750 hPa) in DJF, coinciding with the NH burning season (Sauvage *et al.*, 2004). CO values up to 500 ppbv at 850 hPa underscored the biomass burning influence, although urban-industrial factors are not discounted.

Over central equatorial Africa (Brazzaville, Luanda), the dominant seasonal maximum (80 ppbv at the former station) occurs in June, July, August (JJA), the season of SH biomass burning. Back trajectory analysis traces the occurrence of peaks to biomass burn regions. Brazzaville also exhibits a DJF peak (60 ppbv) in the lower troposphere, which is assumed to come from cross equatorial transport. Luanda, on the other hand has far lower ozone mixing ratios in DJF due to a greater oceanic influence at this time (Sauvage *et al.*, 2004).

Southern Africa (Irene) is characterized by typical anticyclonic re-circulation that leads to a buildup of ozone in the mid-troposphere, a springtime maximum and a marked vertical stratification in ozone due to the stability of the atmosphere. A further characteristic feature is the sub-continental scale plume that exits southern Africa toward the Indian Ocean.

In East Africa, represented by Nairobi, lower tropospheric ozone values are low (10-40 ppbv) throughout the year due to the dominance of south-easterly flow from the ocean. By contrast, in North Africa (Cairo), lower tropospheric ozone is elevated in JJA due to both local pollution sources and long-range low-level transport from Europe.

The role of biogenic sources over sub-equatorial Africa was emphasized, noting that they account for 94% and 98% respectively of CH_4 and VOC emissions and 50% of NO_x emissions (Otter *et al.*, 2001). Emissions from biofuels are increasingly being recognized as important over the African continent.

The 'tropical Atlantic paradox' (Thompson *et al.*, 2000) was highlighted by many presenters and further insights to this feature given. These included the possible contribution of long-range easterly transport of South Asian pollution from the Indian Ocean to the Atlantic Ocean (Chatfield *et al.,* 2004). MOZAIC profiles at West African stations (Lagos and Abidjan) in the DJF period also showed evidence of pronounced lower tropospheric ozone enhancement, in contrast to satellite results. The well known 'zonal wave-one' feature (Thompson *et al.,* 2003), in which tropospheric ozone maximizes between 40°W and 60°E was also highlighted and evidence presented for a contribution from the lower troposphere (750 hPa), based on an analysis of MOZAIC data.

The springtime accumulation of tropospheric ozone in the SH subtropics due to the anticyclonic re-circulation of air, extended periods of strong insolation and the multiple sources of ozone precursors (biomass burning, lightning, biogenic and urban-industrial sources) emphasizes this region to be a 'giant natural photochemical reactor'. Lusaka, in Zambia, is suggested as the core collector region due to the particularly high surface ozone and total tropospheric ozone (TTO) amounts observed there (> 50 DU in spring according to Thompson *et al.,* 2002).

A number of papers stressed the importance of stratospheric-tropospheric exchange (STE) in the tropospheric ozone budget. A distinction was made between deep STE, including tropopause fold events, which is seasonally varying and likely to be important over parts of North Africa; and transient STE, which is governed by isentropic mixing processes across the tropopause. Case studies of STE in association with the subtropical jet stream in the Southern Hemisphere (Baray *et al.,* 2003) and deep convective systems such as tropical cyclones were also presented.

Clearly, a range of sources contributes to the tropospheric ozone budget and the interplay over the African continent provides a natural laboratory in which to investigate these components (Fig. 1).

Variability in tropospheric ozone and the challenge that this posed in providing a meaningful average statistics was alluded to by a number of presenters. Attempts to overcome the problem of the 'meaningless mean' were described and included the classification of ozone profiles by means of a multivariate cluster analysis (Diab *et al.*, 2003), a principal components analysis and self-organizing maps. Conclusions supported the division of ozone profiles into smaller homogenous groups that would permit inferences to be made about source regions of ozone precursor gases and likely dynamical influences.

Measurements from many ongoing programmes (for example SHADOZ, MOZAIC, GAW) and recent campaigns (for example SAFARI-2000) formed the basis of much of information presented. The need for ongoing measurements and campaigns in this traditionally data sparse region of the globe was endorsed by all presenters.

Future campaigns over Africa were discussed, in particular AMMA (African Monsoon Multiple Analysis), which is focused on an improved understanding of interactions between multiple emissions in the West African monsoon region, the role of dynamics and the mechanism of outflow from West Africa to the global troposphere.

Some of the major gaps that were identified at the workshop included a need for a regional modeling focus over Africa, the need to improve emissions estimates, and the need to integrate research results to provide an holistic understanding of tropospheric ozone variations over the continent. The benefits flowing from this nascent network of scientists with an African focus were apparent at the workshop and a decision to try to sustain and develop it into the future was taken.

References

Baray, J.-L., G. Ancellet, M. Bessafi, A. Badr, S. Baldy, P. Keckhut, Subtropical tropopause break as a possible stratospheric source of ozone in the tropical troposphere, *J. Atomos. and Solar-Terr. Phys.,* 60, 27-36, 2003.

Chatfield, R.B., H.Guan, A.M. Thompson, J.C. Witte, Convective lofting links Indian Ocean air pollution to paradoxical South Atlantic ozone maximum, *Geophys. Res. Lett.,* doi: 10.129/2003GL018866, 2004.

Diab, R.D., A.Raghunandan, A.M. Thompson, V. Thouret, Classification of tropospheric ozone profiles over Johannesburg based on MOZAIC aircraft data, *Atmos. Chem. Phys.*, 3, 713-723, 2003.

Otter, L.B., L. Marufu, M.C. Scholes, Biogenic, biomass and biofuel sources of trace gases in southern Africa, *S.A. J. of Sc.,* 97 (3-4), 131-138, 2001.

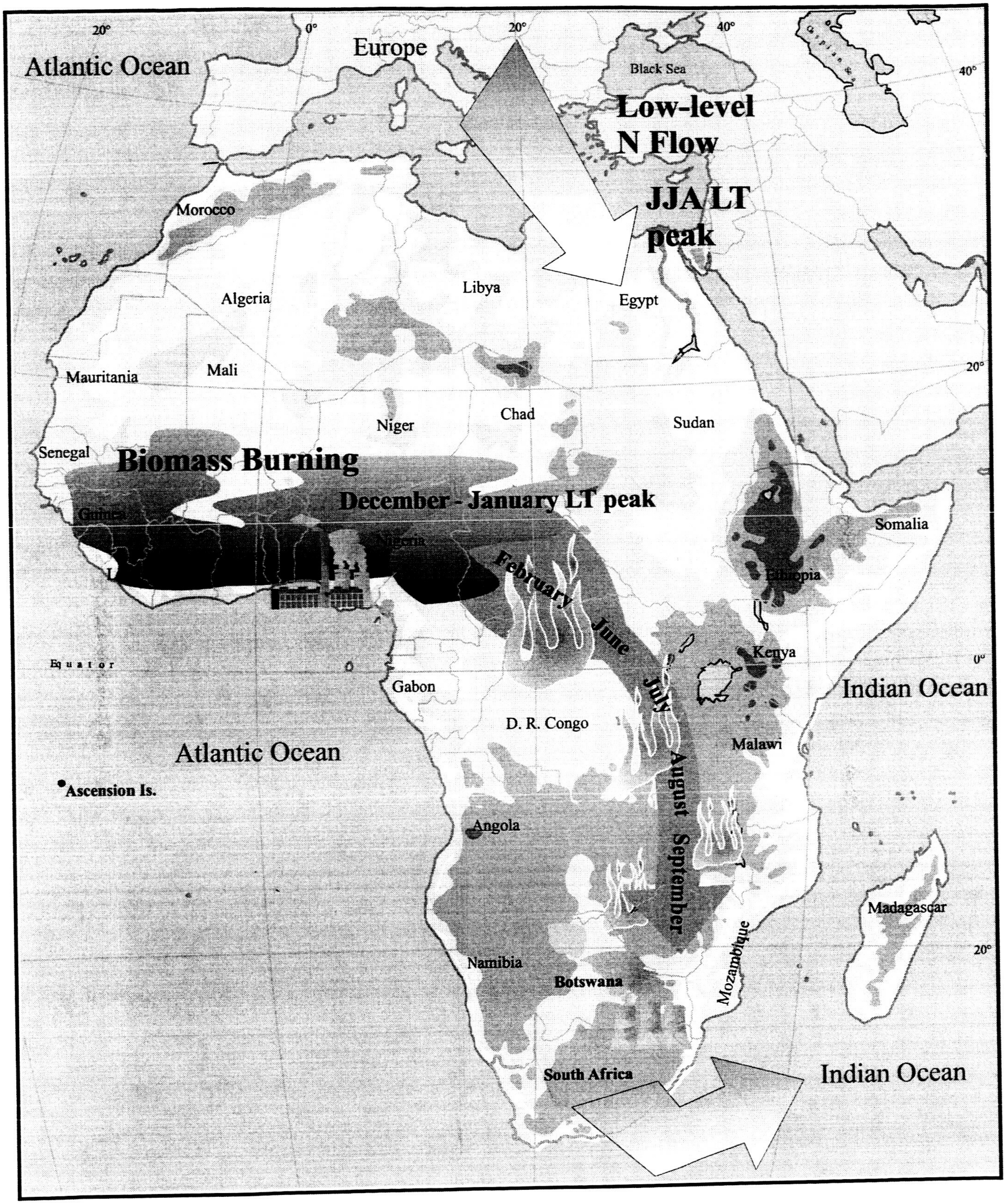
Thompson, A.M., B.G. Doddridge, J.C.Witte, R.D.Hudson, W.T. Luke, J.E. Johnson, S.J. Oltmans, R. Weller, R., A tropical Atlantic paradox: shipboard and satellite views of a tropospheric ozone maximum and wave-one in January-February 1999, *Geophys. Res. Lett.,* 27 (20), 3317-3320, 2000.

Thompson, A.M., J.C. Witte, M.T. Freiman, N.A.Phahlane, G.J.R. Coetzee, Lusaka, Zambia, during SAFARI-2000: convergence of local and imported ozone pollution, *Geophys. Res. Lett.,* 29(20), 1976, doi: 10.129/2002GL015399, 2002.

Thompson, A.M., J.C. Witte, S.J. Oltmans, F.J., Schmidlin, J.A. Logan, M. Fujiwara, V.W.J.H. Kirchhoff, F. Posny, G.J.R.Coetzee, B.Hoegger, S. Kawakami, T. Ogawa, J.P.F. Fortuin, H.M. Kelder, H.M., Southern Hemisphere Additional Ozonesondes (SHADOZ) 1998-2000 tropical ozone climatology: 2. tropospheric variability and the zonal wave-one, *J. Geophys. Res.*, 108, 8241, doi:10.129/2002JD002241, 2003.

Sauvage B., V. Thouret, J-P.Cammas, G.Athier, P. Nedelec, Tropospheric ozone over Equatorial Africa: regional aspects from MOZAIC data, *Atmos. Chem. Phys.,* submitted 2004.

FIG 1



20°
0°
20°
40°
40°
Atlantic Ocean
Europe
Black Sea
Low-level
N Flow
JJA/LT
peak
Morocco
Algeria
Libya
Egypt
Mauritania
Mali
20°
Niger
Chad
Sudan
Senegal
Biomass Burning
December - January LT peak
Guinea
Nigeria
Somalia
February
June
Ethiopia
Equator
Kenya
0°
Indian Ocean
Gabon
July
D. R. Congo
Malawi
Atlantic Ocean
August
Ascension Is.
Angola
September
Madagascar
Mozambique
20°
Namibia
Botswana
South Africa
Indian Ocean

FIG 2